A Numerical Investigation of Flow Focusing in Unsaturated Fracture Networks

Keni Zhang, Yu-Shu Wu, G. S. Bodvarsson, and Hui-Hai Liu
Contact: Keni Zhang, 510/486-7393, kzhang@lbl.gov

RESEARCH OBJECTIVES

The primary objective of this work is to develop numerical models to improve our understanding of discrete flow paths through unsaturated fracture networks. These fracture networks are modeled using fracture data collected from the Topopah Spring welded tuff unit (TSw) of Yucca Mountain, Nevada, the site of the proposed national nuclear waste repository. We try to answer the following questions: How do flow paths develop in the randomly distributed fracture network? How do rock matrix and infiltration rate (on the top boundary) influence flow patterns in the fracture networks? And finally, what is the relation between flow focusing and boundary conditions?

APPROACH

A two-dimensional fracture network was constructed using field fracture-mapping data, including fracture density, length range, and fracture orientations measured at the site. Each fracture in the network is randomly distributed; however, the random distribution is governed by statistical information derived from field-measured fracture data. Statistically, the generated fracture network should correspond to actual fracture distribution in the study domain. Figure 1 shows a fracture network consisting of those fractures intersecting globally connected paths. Isolated fractures are neglected in the simulation. The simulation domain is considered to be combined media, consisting of a fracture network superimposed on a porous matrix.

ACCOMPLISHMENTS

Five simulation cases were run with different matrix rock permeabilities and different infiltration rates. These cases may reflect the influence of matrix rock on flow focusing and the influence of infiltration rate on the flow pattern of the fracture network. The modeling results demonstrate that focused flow paths through fractures are generally vertical (Figure 1). Simulation results suggest that the average spacing between flow paths in a layered system tends to increase with depth as long as flow is gravity-driven. In addition, flow paths are found to consist primarily of long trace fractures in lower fracture-density domains. In higher fracture-density domains, long and short trace fractures both contribute to the development of flow paths.

SIGNIFICANCE OF FINDINGS

The majority of fluxes along flow paths have low normalized fluxes (ranging from 0 to 2). The higher normalized flux is caused by the higher degree of focusing into several fracture paths. Simulation results indicate that lower matrix-rock permeability will lead to a larger flow-focusing phenomenon. Flow focuses into only a few fractures and forms two main flow paths. Each flow path spreads over a range of several meters. Simulation results thus indicate that the impact of infiltration rate on flow focusing may be insignificant for unsaturated flow in a fracture network.

RELATED PUBLICATIONS

Zhang, K., Y.S. Wu, G.S. Bodvarsson, and H.H. Liu, Flow focusing in unsaturated fracture networks: A numerical investigation. Vadose Zone Hydrology, 2003 (in press); Berkeley Lab Report LBNL-52819, 2003.

Zhang, K., Y.S. Wu, G.S. Bodvarsson, and H.H. Liu, Determination of unsaturated flow paths in a randomly distributed fracture network. Proceedings for Probabalistic Approaches and Groundwater Modeling Symposium, World Water and Environmental Resources Congress, Philadelphia, Pennsylvania, 2003.

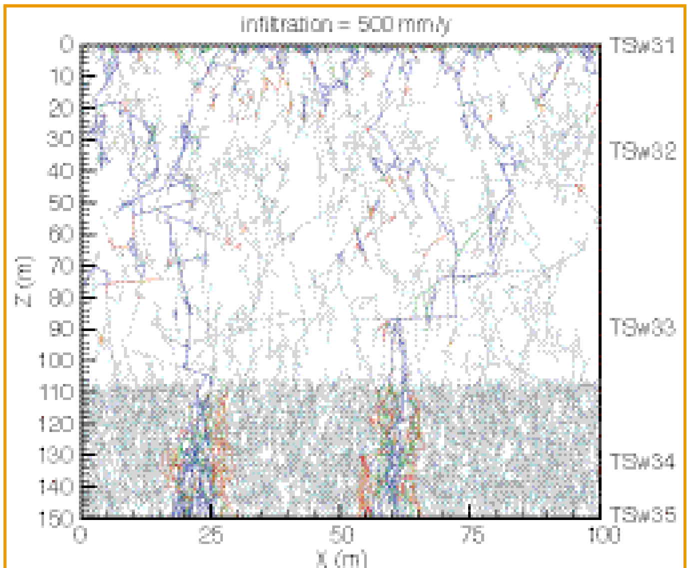

Figure 1. Simulated steady-state flux distribution in the fracture network, matrix permeability = 0; infiltration rate = 500 mm/year. Flux magnitude is represented by four different colors (in decreasing sequence): blue, green, red and grey. Each color represents a one-order-of-magnitude difference in flux.

ACKNOWLEDGMENTS

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